(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

UNITED STATES NAVY · NAVAL POSTGRADUATE SCHOOL ·

THESIS

EVALUATION OF VHF INTERCEPT
AND DIRECTION FINDING SYSTEMS

by

Muhammad Aleem Siddiqui

September 1989

Thesis Advisor: Donald L. Walters

Approved for public release; distribution is unlimited

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified

1b RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School

6b OFFICE SYMBOL (If applicable): 61

7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School

6c. ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code):

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): EVALUATION OF VHF INTERCEPT AND DIRECTION FINDING SYSTEMS

12 PERSONAL AUTHOR(S): SIDDIQUI, Muhammad Aleem

13a TYPE OF REPORT: Master's Thesis

13b TIME COVERED: FROM ______ TO ______

14 DATE OF REPORT (Year, Month, Day): 1989, September

15 PAGE COUNT: 91

16 SUPPLEMENTARY NOTATION:

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Electronic Warfare, Interception, Direction Finding

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis evaluates VHF Intercept and Direction Finding (DF) collection systems developed by ESL International, Watkins Johnson, and HRB Singer for induction into a divisional level signal battalion of the Pakistan Army. The introduction of the proposed system is expected to enhance existing intercept and Direction Finding (DF) Capabilities. This thesis evaluates the three systems on the basis of performance, design, and supportability characteristics. In the process each system element is further broken into subelements composed of significant intercept and DF system characteristics. The expected threat environment and the capabilities of modern intercept and DF systems provided practical and workable rationale and criteria for this purpose.
The conclusion is that the system developed by ESL International offers significant capabilities of meeting the needs of expected divisional level

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Donald L. Walters

22b TELEPHONE (Include Area Code): 408-646-2267

22c OFFICE SYMBOL: 61We

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 Unclassified

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

Block 19, Abstract.

threat environments. A major recommendation is that the system capabilities be verified by carrying out a dedicated operational testing program before finalizing the acquisition proposal.

Approved for Public Release; distribution is unlimited

EVALUATION OF VHF INTERCEPT AND DIRECTION FINDING SYSTEMS

by

Muhammad Aleem Siddiqui
Major, Pakistan Army
B.S., Military College of Signal, Pakistan, 1986

Submitted in partial fulfillment of
the Requirements for the degree

MASTER OF SCIENCE IN SYSTEMS ENGINEERING
(ELECTRONIC WARFARE)

from the

NAVAL POSTGRADUATE SCHOOL

September 1989

Author: ______________________________
Muhammad Aleem Siddiqui

Approved by: ______________________________
Donald L. Walters, Thesis Advisor

____
Dan C. Boger, Second Reader

____
Joseph Sternberg, Chairman
Department of Electronic Warfare

ABSTRACT

This thesis evaluates VHF Intercept and Direction Finding (DF) collection systems developed by ESL International, Watkin Johnson, and HRB Singer for induction into a divisional level signal battalion of the Pakistan army. The introduction of the proposed system is expected to enhance existing intercept and Direction Finding (DF) capabilities. This thesis evaluates the three systems on the basis of performance, design, and supportability characteristics. In the process each system element is further broken into subelements composed of significant intercept and DF system characteristics. The expected threat environment and the capabilities of modern intercept and DF systems provided practical and workable rationale and criteria for this purpose.

The conclusion is that the system developed by ESL International offers significant capabilities of meeting the needs of expected divisional level threat environments. A major recommendation is that the system capabilities be verified by carrying out a dedicated operational testing program before finalizing the acquisition proposal.

TABLE OF CONTENTS

I. INTRODUCTION

A. GENERAL

Electronic devices have become an essential part of a military force for command and control, logistic support and control of weapons. On one hand, use of such electronic devices extend excellent command and control opportunities, and on the other, their increased use has inherent risks and vulnerabilities. These dangers have established themselves as important weapons of war. The threat of Electronic Warfare (EW) is fact and in any future war we will have to face an organized electronic warfare effort by the enemy. Electronic warfare is becoming one of the most effective weapons in the armory of any nation facing a sophisticated threat. Properly used in support of a tactical plan, electronic warfare can turn out to be a battle winning factor. Therefore, the need for having a sizable capability in this area must be considered.

Because of its clandestine nature and the high security barriers erected around it, EW is one of the least-understood aspects of military activity of our times and has for many come to represent a "black art" to which only a chosen elite are permitted access. To some extent this is necessary, since electronic warfare must by its nature keep its secrets, as far

as possible, to be effective. On the other hand, electronic warfare must absorb the latest advances in electronics technology if they are perceived to be of potential value.

Despite these factors, electronic warfare is not fundamentally a complex subject and is as old as the technology of electronics itself. Historically, electronic warfare in its most basic form, that of interception of other people's communication has been with us almost since the introduction of communication via radio. As soon as radio communications came into general use, there was always some unauthorized person prepared to eavesdrop on them. Apart from realizing that he may be overheard, there was little that the user could do to counter this.

In the modern electronic battle field, communication plays a pivotal role to control forces, to know their deployment and maneuvers, and to fire weapons. Thus, there are tactical reasons for the presence and activity of each transmitter. Each higher headquarters needs two-way communications with each of its subordinate headquarters; each element of a fire control network must talk to other elements; and each mobile unit must communicate with its commander. Under this saturated communication scenario modern intercept and direction finding (DF) systems provide timely and accurate information that allow a decision maker to determine the strength and location of enemy forces and enemy tactical

intentions. They also support electronic countermeasures (ECM) activities, which can prevent the enemy from effectively controlling his forces or using his weapons. Thus a clear understanding of the theoretical basis of selected electronic warfare (EW) missions, the concept of combat communication, and the characteristics of the latest intercept and DF systems is essential.

B. OBJECTIVE

The objective of this thesis is to evaluate the technological capabilities of VHF Intercept and Direction Finding (DF) systems which could support the combat signal communication at divisional level in the Pakistan Army.

II. ELECTRONIC WARFARE (EW) MISSION CATEGORIES

A. GENERAL

Broadly speaking, Electronic Warfare is a military action involving the use of electromagnetic energy to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum and action which retains friendly use of the electromagnetic spectrum. The commonly employed definition, however, is more restrictive. The term "electronic warfare" includes only those devices designed to interfere with, or prevent such interference with, the operation of military systems that employ electromagnetic communications links. A communication link is any system that conveys information from one point to another. This includes voice and data links, electromagnetic remote sensors such as radar and infrared detectors, and radio navigation systems. The most extensive employment of electronic warfare includes radar systems. In this thesis the discussion considers only communication systems.

Electronic Warfare (EW) involves three major categories; electronic reconnaissance (ER), electronic countermeasure (ECM), and electronic counter countermeasures (ECCM). "Electronic reconnaissance is that branch of electronic warfare involved in gathering, by electronic means,

information concerning the intentions and operations of the enemy and the capabilities and characteristics of his "communications" equipment. Electronic countermeasures is that branch of electronic warfare involved in degrading the usefulness of the enemy's "communications" equipment. Electronic counter countermeasures is that branch of electronic warfare involved in preventing the electronic countermeasures of the enemy from degrading the usefulness of communications equipment employed by friendly forces. [Ref. 1]

This thesis will focus on the electronic reconnaissance area. A brief review of the Electronic Warfare categories is helpful.

B. ELECTRONIC RECONNAISSANCE (ER)

The gathering of information in support of electronic warfare activities takes place at three levels: the strategic level, the tactical level, and the combat level.

Strategic Electronic Reconnaissance (ER), is called electronic intelligence (ELINT) and involves a long term process of large amounts of data and extensive analysis. Usually ELINT data are acquired by long-range signal-monitoring (intercept) receivers from positions removed from the combat zone and are typically used in the design of electronic warfare equipment and the performing of strategic planning.

Tactical ER, generally called electronic support measures (ESM), involves the gathering of information for use in current (daily) operations. The intercept equipment is generally located (at least temporarily) in the combat zone and the analysis of data is more or less limited to determining the locations and types of equipment currently deployed by the enemy. As the name implies, tactical ER data is used to perform tactical planning and to employ electronic warfare equipment to meet current threats. [Ref. 1; p. 1.3]

Combat ER, also called electronic support measures, identifies immediate threats and targets. Because of the urgency, data analysis and presentations are usually automated and, therefore, minimal. [Ref. 1; p. 1.4]

The equipment used in electronic support measures also gathers intelligence, known as radiation intelligence (RINT), and telemetry intelligence (TELINT). RINT and TELINT are a part of ELINT. Radiation intelligence (RINT) is defined as "intelligence derived from the collection and analysis of non-information bearing elements extracted from the electromagnetic energy unintentionally emanated by foreign devices, equipments and systems excluding those generated by the detonations of atomic or nuclear weapons. Many devices such as vehicle ignition systems and power generators give off detectable electromagnetic emission which, if not suppressed, can yield useful intelligence to the enemy. Telemetry

intelligence (TELINT) is defined as the "technical and intelligence information derived from the interception, processing and analysis of foreign telemetry. In this context, the telemetry is usually associated with such things as missile and aircraft tests. [Ref. 2; p. 120]

C. ELECTRONIC COUNTERMEASURES (ECM)

Electronic countermeasures are of two types - jamming and deception. Jamming prevents or disrupts the passage, receipt, or gathering of information by electronic means. Electronic deception feeds false information to the enemy, either through their electronic collection devices or directly to their electronic systems. All types of electronic equipment are vulnerable to both jamming and deception.

Jamming deliberately radiates or reradiates electromagnetic energy to prevent or degrade the reception of information by a receiver. A jammer delivers more power to the receiver preventing the receiver from receiving its intended signal. In general, the effectiveness of jamming depends on the relative power between transmitter and jammer; relative distance between transmitter, jammer, and receiver; terrain barriers; and whether or not the receiver is using a directional antenna.

Communications jamming interferes with enemy communication systems. Used against secure communication systems, it may

force the enemy to transmit in the clear so that the communications can be exploited for combat information. Jamming also can aid in direction finding (DF) by forcing the enemy to transmit longer, allowing time for multiple lines of bearing (LOB) from different directions.

Jamming against communications equipment is accomplished using spot, sweep, or barrage jamming.

Spot jamming may utilize a single frequency or multiple frequencies through:

a. Sequential spot jamming, in which various frequencies are jammed one at a time, in sequence.

b. Simultaneous multi-spot jamming, in which several frequencies are jammed at the same time.

In both spot and sequential spot jamming the full power of the jammer suppresses one frequency at a time, which increases the effectiveness and range of the jammer. The main disadvantage of spot jamming is that receivers can resist spot jamming by slightly changing (detuning) the frequency they are receiving.

In sweep jamming, the jammer goes through a frequency range then repeats the sweep continuously. All frequencies in the range are jammed and friendly frequencies may be affected.

Barrage jamming spreads the jammer's power over a much larger portion of the frequency spectrum than spot jamming,

thereby reducing the radiated power directed at any single target frequency. It is similar to sweep jamming because there are no frequencies free of jamming within the targeted portion of the spectrum.

The advantage of barrage jamming is that more frequencies can be jammed at the same time. The disadvantages are that friendly frequencies may be jammed. Also, spreading the jammer's power over a greater portion of the spectrum reduces the amount of power available to jam each frequency, reducing the effectiveness and range of the jammer.

The jamming signal may include an unlimited variety of amplitude, frequency, or pulse modulating signals. The capability of the jamming equipment, the nature of the signal to be jammed, and the desired result determine the type of modulation.

Reradiation jamming uses special equipment to receive the enemy's transmissions, alter them in some way, and reradiate the signal back to the enemy. The principal targets of reradiation jamming are radars and navigation aids.

Electronic deception misleads the enemy in the interpretation or use of information received by his electronic systems. Normally, it is a part of a larger deception operation and is seldom conducted alone. Electronic deception has the following three forms:

a. Manipulative electronic deception

b. Simulative electronic deception

c. Imitative electronic deception

Manipulative electronic deception alters the electromagnetic profile of friendly forces. It seeks to counter hostile EW and SIGINT activities by manipulating friendly electromagnetic emissions. The objective of manipulative electronic deception is to have the enemy analysts accept the information as valid and thereby arrive at an erroneous conclusion concerning friendly activities and intentions.

Simulative electronic deception misleads the enemy as to the actual composition, deployment, and capabilities of the friendly forces. It seeks to counter hostile EW and SIGINT efforts by simulating non-existing units or capabilities or by simulating actual units or capabilities at false locations.

Imitative electronic deception injects false or misleading information directly into enemy communication networks. The communication imitator gains admission as a substation of a particular radio net and maintains that role until the desired false information is passed to the enemy.

D. ELECTRONIC COUNTER - COUNTERMEASURES (ECCM)

Electronic warfare also involves actions taken to retain friendly use of the electromagnetic spectrum. Maintaining

effective, friendly communications on the battlefield depends upon the solid base of tried and proven ECCM techniques. The sole purpose of ECCM techniques is to ensure the continued friendly use of electromagnetic spectrum for communications.

A close relationship exists between ECCM and Communication Security (COMSEC). Both of these defensive arts are based on the same principle. The major goal of COMSEC is to ensure that the friendly use of the electromagnetic spectrum for communications is unexploitable by the enemy and to ensure security of transmission; whereas, the major goal of practicing sound ECCM techniques is to ensure the continued effective use of the electromagnetic spectrum.

ECCM should be preventive in nature. It should be planned and employed to force the enemy to commit more jamming, information gathering, and deception resources to a target than it is worth or than he has readily available to him. ECCM techniques must also force the enemy to doubt the effectiveness of his jamming and deception efforts.

Preventive ECCM techniques are methods employed to safeguard our communications from disruption and destruction attempted by the enemy. These techniques include all measures taken to avoid enemy detection and to deny enemy intelligence analysts useful information. There are two categories of preventive ECCM techniques:

a. ECCM designed circuits (equipment feature)

b. Radio operating procedures/transmission control

Remedial ECCM techniques reduce the effectiveness of enemy efforts to jam our radio nets. They apply only to enemy jamming efforts or any unidentified or unintentional interference which disrupts our ability to communicate. Here, prevention is the only solution. We must attempt to prevent enemy jamming and interference; but if we don't succeed, then we must take the following actions to overcome it:

a. Recognize jamming / interference:

   1) Determine whether the interference is internal or external to the radio.

   2) Determine whether the interference is jamming or unintentional interference.

b. Overcome jamming / interference by:

   1) Continuing to operate

   2) Improving signal-to-jamming ratio

      (a) Adjust the receiver

      (b) Increase transmitter power output

      (c) Adjust or change the antenna

      (d) Establish a retransmission station

      (e) Relocate the antenna

   3) Using an alternate route for communication

   4) Change frequency

III. CONCEPT OF COMBAT COMMUNICATION IN A DIVISION

A. ELECTROMAGNETIC ENVIRONMENT

In the past, soldiers recognized two dimensions of the battlefield - width and depth. The advent of aircraft forced the recognition of the airspace as a third dimension.

Today another dimension of the battlefield must be considered. Men of perception realize that the "electromagnetic environment" has an ever increasing role in modern tactics and combat. It's the dimension in which radios, radars, and lasers operate. It pervades the other three dimensions of the battlefield. This dimension is limited only by the frequency spectrum and is measured in terms of electronic emitters. The location of each of these emitters is a critical intelligence activity.

The numbers of electronic devices operating in future wars will be staggering. For example, one division has over 1000 electromagnetic emitters, and to this must be added the thousands of emitters in adjacent divisions. Also we must consider the communications used by the civilians in the area of operations, plus those of the enemy forces. One can clearly imagine that we are going to have to fight for our share of the frequency spectrum. And since we are already at a disadvantage on a man-against-man basis, we have got to be

better at gaining and keeping control of the frequency spectrum than the threat force.

Threat forces also know that the key to success in combat is an effective communication system. To defeat us, they must attack and destroy our system. They will use electronic warfare (EW) to destroy as many command, control, intelligence and weapon communication systems as possible. Their major electronic offensive will happen during the first minute of the first battle.

Our ability to counter their electronic warfare (EW) effort will mean the difference between winning and losing. Electronic communications is not something separate from the combat scene; it is a part of the total weapons system and, as such, requires flexible tactics for employment. The communicators are responsible for the proper use of this essential part of combat power, and we must know how to handle it.

B. ROLE AND RESPONSIBILITIES OF THE SIGNAL CORPS

Responsibility for providing communications is shared between the signal corps and the other arms/services. Armor, artillery, engineers, and infantry units in corps and divisions are responsible for regimental/battalion communications from unit headquarters downwards.

The signal corps provides and coordinates all communications in the army down to the point where they are taken over by regimental/battalion units. In addition signals corps is responsible for communication intelligence. On the enemy side of the border, a similar concept of combat communication exists. To insure effective communication intelligence, it is necessary to have a broad look at the means of communications available in the field and their use in various operations of war.

C. COMMUNICATION TECHNIQUES

Information takes many forms and the means to communicate it ranges from the simple to the complex. The system required depends on the type of information to be transmitted, the form in which it will be received and the security and speed required.

D. RADIO

Radio systems are identified by their electronic characteristics. The following is a general list of radio equipment characteristics. Some combinations of these will identify any given division radio and help to fit it into the system being designed:

a. Frequency band:

1) High frequency (HF): 2-30 MHZ

2) Very high frequency (VHF): 30-300 MHZ

b. Type of modulation:

   1) Frequency modulation (FM)

   2) Amplitude modulation (AM)

c. Channel capacity: Single channel

d. Modes of operation:

   1) Voice

   2) Secure voice

   3) Frequency shift keying (FSK)

   4) Radio teletypewriter (RTT)

   5) Single sideband (SSB)

Radio is the most widely used means of communications in a division. It is also the most susceptible to enemy electronic warfare (EW) activities. The communicator must have a full understanding of the capabilities, limitations, and technical characteristics of the radios employed on the battlefield during various operations of war. Improper installation, operation and maintenance may bring defeat just as quickly as other tactical blunders.

Cryptographic security devices are another important aspect of the tactical radio system. These devices connect to single channel radio sets and encrypt either voice or teletypewriter traffic, depending upon the security device used.

Radio has a big disadvantage, too. Radio direction finding (RDF) combined with other intercept and DF analysis provides an accurate picture of our situation and positions to enemy observers.

E. WIRE AND CABLE SYSTEM

In the division, field wire and cable systems provide:

a. Telephone service within command posts and major headquarters.

b. Telephone trunk circuits between unit switchboards at brigade, division artillery, and below

c. Telephone circuits from multichannel terminal equipment to subscribers and switchboards

d. The primary means of communication when radio silence is necessary

There are some obvious advantages in using wire and cable systems in a tactical situation. They eliminate the enemy's ability to locate positions with radio direction finding equipment. They also limit his ability to jam and otherwise disrupt communications.

There are some disadvantages too. The distance between subscribers; the time required for installation; maintenance and recovery; and the user's need for mobility restrict wire and cable use. Also, a wire and cable system, if it is not properly installed, is extremely susceptible to enemy

artillery and damage by our own tanks, armored personnel carriers and other tracked vehicles.

F. RADIO RELAY

Multichannel VHF radio relay systems provide a standby to wire and cable systems in a division. Though it offers directional communication, it is still susceptible to enemy electronic warfare (EW) activities. Sound technical and tactical considerations must govern its employment. Cryptographic security devices are another important part of the radio relay system. Antenna location must meet both technical and tactical requirements. Efficient operation of the system requires coordination between radio relay terminal, multiplex and main system control. The following is a list of radio relay equipment characteristics:

a. Frequency band:

   1) Very high frequency (VHF): 30-300 Mhz

   2) Ultra high frequency (UHF): 300-600 Mhz

b. Type of modulation: Frequency modulation (FM)

c. Channel capacity: 4, 12 and 24 channels

d. Modes of operation:

   1) Voice

   2) Secure voice

   3) Frequency shift keying (FSK)

   4) Radio teletypewriter (RTT)

e. Type of multiplex equipment:

   1) Frequency division multiplexing (FDM)

   2) Time division multiplexing (TDM)

G. MESSENGER SERVICE

The classification of messenger service depends on the type of messenger. A well planned and coordinated system will include foot, motorcycle, jeep, and air messengers, as needed. Messengers provide a secure means of delivery for packages/ messages, but the availability of personnel and transportation and the tactical situation itself limit the service. Despatch rider service is either scheduled or special. Scheduled service has a pre-arranged schedule. Special service, on the other hand, occurs when special handling or more rapid service is required.

H. COMMUNICATION FOR DEFENSE

In order to fight a defensive battle successfully, a commander must receive information quickly and be able to act on that information by passing orders. The attack may come at any time and from any direction. If it is to be broken up, the commander must be able to concentrate his infantry, artillery, and air at the right place without delay. It is the responsibility of the signal corps to produce a sound communication system which will enable centralized control to

be exercised quickly and which is not likely to fail at the critical time. The communication means to be employed and available with signal corps are as follows:

Ground lines, with their greater traffic capacity, security and simplicity will form the backbone of the communication system in defense. Signal corps communication at all levels coordinates all line networks in the operational area and lays down the priorities for laying and burying of lines. Normally artillery and signals communications complement each other and act as alternative channels. Continued and progressive improvements make the line system safe and provide alternative routes. Reserve forces held for counter attack mainly rely on line communication since they observe electronic silence until they are committed to battle.

Defensive operations seldom use multichannel VHF/UHF radio relays. Radio relays may be used in the initial stages when the line network is being laid out. However, there is a possibility of its use of providing communications to a covering force if it is large and is comprised of all arms elements.

Radio (HF/VHF) will always be a secondary means of communication, but it is a good standby to line and radio relay. All formations and units exercise radio silence in the defense but the counterattack force keeps it ready and immediately uses it upon engaging. Radio may be the chief

means of communication for the covering troops since they are highly mobile and operate at distances far from the main defenses. Similarly, air support uses radio to assist in breaking up enemy attacks. Radio may also be used for pure deceptive roles to give the enemy a false impression regarding dispositions, strength, etc.

I. COMMUNICATION FOR OFFENSIVE OPERATIONS

The frequent moves of headquarters, changes in grouping, and the increase in distances between them present considerable communication problems in the advance. It will help in maintaining good communication if headquarters are kept well forward and moved in as large bounds as possible. During this phase the divisional signal resources are preserved as much as possible to ensure their availability on contact with the enemy.

Radio is the primary means of communication when headquarters are on the move and facilities are not tied down to static positions. During the move, interference, both atmospheric and electrical especially on HF sets, will reduce the effectiveness of this means of communication considerably. Enemy jamming capabilities may at times render a net or a complete band useless. During the advance, it may become necessary to impose radio silence for security and deception purposes.

Radio relay communication characteristics make it extremely adaptable to the conditions before contact with the enemy. The relay links are normally used in leap-frog arrangement. This system eliminates the time lag imposed by laying line communication and provides efficient communication. The system does not offer security, especially in the forward areas and is susceptible to jamming by the enemy. Using radio relay, in preference to lines, preserves the line resources for use at a later stage.

Land lines are still valuable in the advance. Their usefulness will depend largely on the rate of advance and the accuracy with which further locations of headquarters can be forecast. The advisability of laying cable during even the very slowest advance is carefully weighed against the time and space factor, resources available, likely future requirements, etc.

J. COMMUNICATION FOR ATTACK AND PURSUIT PHASE

A major attack starts from a position with fully developed line communications (as in the defense). Communications become progressively harder to maintain as the attack develops. Radio and, to a certain extent, radio relay take over most of the channels of communication from lines.

Line communication ensures maximum signal security when the attacking units are in their assembly area, just before

the attack. Once the assault and destructive phase have started, all available means of communication are used.

Radio silence may be partial or total during the preparatory phase for the purpose of security or deception. Here the air support communications are as important as normal command radio communication. During the assault phase, radio becomes the primary means of communication. Similarly, during the pursuit phase, radio provides intercommunication to and within the pursuit force.

Radio relay links are more secure in rear areas behind divisions than in forward areas, where they are as unsafe as radio from a security point of view. But the characteristic of radio relay makes it the backbone of rearward communication of the pursuit force, whenever its headquarters becomes stationary. Relay stations become essential when the distance to the pursuit force increases.

K. COMMUNICATION FOR WITHDRAWAL

In the withdrawal, distances between headquarters tend to be stretched and headquarters are often split to allow for control on one position and reconnaissance and coordination on another. Signal resources are likely to be taxed to the limit in the withdrawal, since they do not cater to the splitting of headquarters for prolonged periods. In addition, step-up, traffic control, and administrative purposes require

radio communication. In withdrawal existing land lines and radio relay communication links usually will be available to fall back upon. It may be necessary to lay short spurs or an additional radio relay station to bridge gaps in line or radio relay systems. But when the withdrawal is to a position away from the existing arteries or when the enemy attempts to envelop the force and succeeds in cutting the lines of communication, the task of providing the communication becomes more difficult. It is quite likely that line and radio relay communication will be impossible, and radio will become the principal means of communication. However, radio relay can be used to great advantage. In withdrawal the secrecy of intention, timing, route, grouping and the new defensive positions are important and the communication system, whatever it may be, must deny all this to the enemy.

When withdrawal is along the existing cable arteries; satisfactory line communication to the rear and forward troops is quite simple by laying short spurs from the main artery. Hasty withdrawal may force routes other than existing main arteries; then radio will be the principal means of communication. Withdrawal may create panic, confusion, and poor discipline. Therefore control in general and rearward traffic control in particular requires special separate traffic control communication.

Radio silence may be partial or complete since secrecy in withdrawal is essential. This is of course weighed against the loss of control. At times imposing of radio silence gives away what it would not otherwise, and this is more likely to be the case in withdrawal. Withdrawal may require several routes. Since radio is independent of the restrictions imposed by the routes of existing lines it is deployed to the fullest extent within the limits imposed by radio silence. Radio, due to its flexibility and mobility, is most useful and will probably be the principal means of communication during withdrawal, particularly for covering troops or rear-guard due to their mobile nature.

Radio relay multichannel networks should be coordinated in such a way that the existing terminals and relays in the rear should be used by the headquarters withdrawing, along the same axis. If there are no restrictions on the use of radio, radio relay stations should be used to bridge the gaps in line communication. This allows the line parties to reel up, provided the time and the tactical situation permits. Setting up of relay stations is unsafe and time consuming during withdrawal.

IV. MODERN TECHNOLOGICAL CONCEPTS IN COMMUNICATION

A. GENERAL

Communication warfare is an element of warfare that pits potential communicators against hostile personnel who seek to intercept or disrupt their communication. In the armies of developed countries, covert communication techniques have cut down the possibility of intercepting and interpreting communications.

Various general measures will reduce communication susceptibility to interception and jamming severely. Using frequencies exceeding 30 MHZ will minimize the long range interception and jamming possibilities, since ionospheric reflections are small. Similarly, millimeter waves and highly directional laser beams are difficult to intercept. Their receivers are difficult to jam due to the narrow radiation patterns of the receiving antennas. Special applications such as satellite communication can eliminate these problems.

Cable communication by metallic wires, coaxial cable, wave guides and by optical fibers provide advantages similar to those of directional beams, but without the acquisition problem. The main problems with cables are their impracticality in mobile, rapidly changing tactical

environments and their susceptibility to damage. Since optical fibers do not emit a significant amount of electromagnetic energy, they are very effective in preventing the interception of communications by the enemy. Tapping is more difficult than it is for a metallic cable. Other advantages of optical fiber communication are light weight, lack of crosstalk and invulnerability to jamming. A major disadvantage is the difficulty in rapid replacement of damaged fiber.

Technological advances are providing the "force multiplier" required to command, control, and win battles. At present and in the near future, the technological strides discussed below are taking/will take place. The key to providing effective communication systems is to imbed that technology in new developments and field them as quickly as possible.

B. SPREAD SPECTRUM COMMUNICATION

Spread spectrum communication is one of the most significant innovations. It produces a signal with a bandwidth much wider than the message bandwidth. Because a spread spectrum system distributes the transmitted energy over a wide bandwidth, the signal-to-noise ratio at the receiver is low. Nevertheless, the receiver is capable of operating successfully because the transmitted signal has distinct

characteristics relative to the noise. [Ref. 3]

A pseudorandom noise code controls the waveform. It is a binary sequence that is apparently random, but can be reproduced deterministically by the intended user. The pseudonoise code gives spread spectrum systems identification and selective calling capabilities. [Ref. 3]

Spread spectrum systems are useful for military communications because they make it difficult to detect the transmitted waveform, i.e, low probability of intercept (POI). The system is difficult to jam and offers high data rate from transmission and reception. The most widely used spread spectrum methods are

a. direct sequence (DS) modulation, in which a fast pseudorandom sequence causes phase transitions in the carrier containing data;

b. frequency hopping (FH), in which the carrier shifts frequency in a pseudorandom way; and

c. time hopping (TH), where burst signals are initiated at pseudorandom times. Hybrid combinations of these techniques are frequently used, such as FH/DH/TH. [Ref. 4]

A burst communication system transmits data in a high-speed bit stream, which is closely associated with spread spectrum signals. Here the maximum transmission duration of a bit stream is rarely longer than 30 to 45 seconds. Thus, burst communication systems are less susceptible to detection than other form of tactical communications. Simply by virtue

of their minimal transmitting period, spread spectrum techniques are utilized throughout the frequency range in order to optimize the information carrying capacity under military stressed situations such as jamming and interception. [Ref. 4]

C. METEOR BURST COMMUNICATION (MBC)

Meteor burst communication is based on RF signals bouncing off ionized trails in the atmosphere. The ionized trails of electron are caused by meteorites bombarding the earth's atmosphere. The size of each trail and its duration as a reflecting or reradiatory path of RF signals depends largely on the size of the meteor. The height of these trails range from 85 km to approximately 125 km. Meteor burst systems usually operate at VHF between 30 MHZ and 50 MHZ. The heights and the curvature of the earth limit communication to ranges around 2000 km, but there is no dead space between zero and maximum range, as is the case with HF. [Ref. 4]

In a typical meteor burst system, one station continuously broadcasts a "probe" signal. Receipt of this probe signal by a second station indicates the existence of a usable meteor trail and the second station responds over the reciprocal path. The life time of a useful path ranges from four milliseconds to several seconds. A typical trail lasts for a few hundred milliseconds, with wait time between trails

ranging from seconds to minutes, depending on daily and annual cycles. Each message consists of bursts of high-speed data of tens to hundreds of characters separated by periods of silence. [Ref. 4]

Generally, the "footprint" of the signal is elliptical in shape with major axis in the direction of transmission (typically 30 miles major axis and 15 miles minor axis). This permits multiple use of radio frequencies and provides protection against unwanted intercept and jamming. Additionally, MBC systems don't utilize the ionosphere so they recover from atmospheric nuclear events more quickly than HF systems. [Ref. 4]

In general, two types of MBC systems exist: in telemetry, in which large number of remote stations report weather data to a single master; and in point to point message communications, between two military headquarters or through large systems comprising many nodes. Each key node has master station equipment and may have a larger number of such nodes with remote stations. In addition to the advances made in improving throughput and wait time and in enhancing flexibility, significant improvements have been made in networking software, which enables MBC message communication systems to handle traffic efficiently. Keeping in view the scope of this research work further quantitative discussion on this aspect of MBC is not possible. [Ref. 4]

D. FIBER OPTICS

Using optical fiber systems in tactical operations supports force dispersion and enables high-value targets to remain hidden. Many defense installations are turning to fiber optic transmission systems as the preferred alternative to copper wire, coaxial and microwave systems in new and existing local area networks. There are a number of reasons for this growing interest in fiber optics.

a. Fiber optic cable is dielectric, so it does not bleed off electrical signals and thus provides greater security than traditional systems.

b. Fiber optic cable is immune to electromagnetic pulse, which precludes the potential for electrical serge that can disturb computer operations.

c. Fiber optic systems are well suited to the distributed data environment found at defense installations, since the bandwidth of fiber optic cable is unaffected by the distances of two miles or more.

d. Optical fiber can be extended 10 - 20 km or longer without the need for repeaters.

e. Optical fiber cable occupies far less space than normal copper wire, making it possible to achieve highly efficient transmission while conserving space.

f. Fiber optic transmission systems offer an alternative to circuit crowding because they eliminate the line-of-sight problems associated with microwave transmission.

g. Fiber optic is smaller in size, lightweight, flexible and high tensile strength cable.

h. Fiber optic cable is not affected by electromagnetic interference (EMI) and electromagnetic pulse (EMP).

i. In view of greater bandwidth capability in a given duct space, it proves less expensive than metallic cables. [Ref. 4]

Optical fibers are made from an abundant and inexpensive material, silica SiO_2. There are two types of optical waveguide fibers, i.e., multimode and single mode having diameters 20-150 microns and 1.5-8 microns respectively. Good quality multimode fibers can transmit 1000 Mb/s over 1 km. At the lower rate of 1000 Mb/s, the repeater spacing can be greater, about 10 - 20 km. [Ref. 5]

Single-mode optical fiber systems propagate light rays along a single direct path along the fiber core in contrast to multi-mode systems where the light rays can bounce back and forth on many zig-zag paths as they move along the fiber. Without elaborate multiplexing schemes, single-mode optical fiber systems can transmit, without regeneration by a repeater, up to 200 Mb/s over 80 - 100 km. [Ref. 4]

Fiber optic communication links include a transmitter, a light source, a fiber optic cable, a photodetector and receiver. The light source is a light emitting diode or laser diode that accepts an electrical input signal. The fiber transmits the optical output energy to the signal with some small attenuation and distortion. At the far end, the

receiver photodetector converts the optical energy back to electrical form.

Fiber optic systems can transmit data, voice and video. The system is ideal for synchronous or asynchronous data transmission, particularly at longer distances. Data transmission over fiber usually requires less bandwidth than do voice and video transmission, and it is accomplished via a binary digital signal with a low error rate typically 10^{-9}. [Ref. 5] The significant trend today is toward fiber optic systems that accommodate transmission of both data and voice. This entails the multiplexing of different types of media over the same transmission system.

The choice of network topology depends on specific circumstances, but selection will involve three basic types - star, ring and bus. These are not mutually exclusive, however, because a combination of all three can be used in larger LANs. The factors which must be considered while choosing fiber optic cable include current and future bandwidth requirements, acceptable attenuation rates, length of cable and cost of installation, mechanical requirements, signal source, connectors and terminations, cable dimensions and physical environments. [Ref. 5]

E. MILLIMETER WAVELENGTH

The millimeter wave (MMW) region of the electromagnetic spectrum has received increased interest in recent years due to significant advances in the development of transmitters, receivers, devices and components. The MMW region finds use in systems applications such as radar, radiometry, radio astronomy, missile guidance, communications and spectroscopy.

The MMW region of the electromagnetic spectrum covers the frequency range from 30 GHZ to 300 GHZ (or wave length between 1 cm and 1 mm; 30-300 GHZ is the EHF band). Other current terminology associated with the MMW region includes "near-millimeter waves" for frequencies from approximately 100 GHz (sometimes from 90 GHZ) to 1000 GHZ and sub-millimeter from about 150 to 3000 GHZ.

One characteristic of the MMW frequency range is that for a given physical antenna size (aperture) the antenna beamwidth is smaller and the gain is higher than at microwave frequencies. Therefore, to obtain a specified antenna gain or narrow beamwidth, a much smaller antenna may be used. MMWs are a very promising media for line of sight communications in the lower atmosphere under battlefield environmental conditions. These waves exhibits high data rates and low propagation losses in the 35 GHZ and 94 GHZ atmospheric windows. [Ref. 4]

MMW systems are superior to optical and infrared systems for penetration of smoke, fog, haze, dust, clouds and other adverse environments. The improved technology includes better sources (such as Gunn oscillators, gyrotrons, extended interaction oscillators [EIOs], extended interaction klystron amplifiers [EIKAs], magnetrons and travelling wave tubes) which have higher power outputs or operate at higher frequencies and, in some cases, have longer life times than earlier designs. [Ref. 4]

F. LOCAL AREA NETWORKS (LAN)

Local area networks for army headquarters have the following characteristics: high data rates (.1 - 100 Mbps), short distances (.1 - 50 km) and low error rate (10^{-8} -10^{-11}). Implementing a local network has a number of significant benefits. First, and most important, modifications and enhancements have little impact on the other devices on the network. Therefore, a system evolves gradually rather than through a few major upgrades. Other benefits include higher system availability (critical resources can be duplicated and functions shifted from failed processors to alternate processors with no interconnect problems), sharing of expensive resources, reduction of amount of cabling and interconnections required, easier integration of equipment and functions, and greater flexibility of equipment location. Of

course, local networking does not guarantee interoperability. The network only provides connection compatibility, electrical connectivity and perhaps some lower level protocols. Interoperability requires, in addition, application compatibility, which is not automatically provided by the network. [Ref. 4]

Local area networks are frequently characterized in terms of their topology. Three topologies are common, star, ring, and bus or tree. Modern local networking systems are characterized by bandwidth of consecutive frequencies and high data rates of several million bits per second. These systems use coaxial cable, twisted pair wire, or fiber optic transmission media. [Ref. 5]

G. SATELLITE COMMUNICATION

Over the past several years, the service requirements for satellite communication (SATCOM) have increased steadily to a point where satellites operate at full load capacity. With the advent of SATCOM, links were established easily. They were reliable, stable (nonfading), terrain independent and not affected by the atmosphere. The satellite link is a quasi-channel affected by the atmospheric absorption due to rain and cloud coverage. The effect of rain can be compensated by a nominal downlink margin. [Ref. 4]

In discussing satellite communication, it is difficult to differentiate tactical and strategic communications. A terminal at corps headquarters in the field can just as easily communicate with a division in a tactical environment as it can communicate with the commander-in-chief thousands of miles away regarding a strategic matter. Of course the satellite is indifferent to tactical or strategic traffic. At present time, two frequency bands have been allocated and are being used, i.e., [Ref. 4]

a. UHF Band

Ground to satellite	335.4 - 399.9 MHZ
Satellite to ground	225.0 - 328.6 MHZ

b. SHF Band

Ground to satellite	7.250 - 7.700 GHZ
Satellite to ground	7.900 - 8.400 GHZ

In the Defense Satellite Communication System (DSCS II) a constellation of four satellites provides for global communication. DSCS II is a spin stabilized satellite having both earth coverage and narrow beam antennas. The satellite has four transponders. The transponders are transparent; that is, they receive RF carriers and retransmit the signal on a downlink frequency. One of the transponders, in conjunction with the narrow beam antenna, is used for tactical communications. The coverage area of the narrow beam antenna

has a 2.5 degree bandwidth covering an area of 1,000 miles in diameter at the subsatellite point. [Ref. 4]

Eventually, DSCS III satellites will replace the DSCS II variety. DSCS III is a three axis stabilized satellite with six transponders operating in the 7/8 GHZ band. The satellite uses earth coverage antennas and a 61 beam waveguide lens antennas for receiving the uplink, earth coverage and two 19 beam waveguide lens antennas for the downlink. In addition it also has a dish antenna to service the ground mobile forces (GMF) tactical terminals. [Ref. 4]

The GMF Satellite Communication System (GMFSCS) will satisfy critical command and control multichannel transmission requirements between command echelons from theater army down to maneuver brigade level. The terminals can provide command and control links between air defense, artillery brigade and other groups.

GMF requirements for satellite communication falls into two broad categories of data rates: high data rate, full duplex multichannel trunking and low data rate for netting operations. While multichannel trunking uses the SHF band, single channel netting utilizes the UHF band.

Satellites are vulnerable to electronic and physical attack. Electronic countermeasures can protect SATCOM from intentional interference. L ›reading the information over a large bandwidth, either by direct pseudonoise sequence,

frequency hopping or both. Physical attack of a synchronous satellite would require placing an antisatellite (ASAT) weapon in the vicinity of the satellite (22,300 miles) or from directed energy beam weapons which would require large expenditures by the attacker.

Future satellite communication systems will provide the following:

a. Survivability - satellites will be hardened against physical, nuclear effects and electronic jamming.

b. Increased Interoperability - through standardized waveforms, signal processing and encryption devices.

c. Processing Satellite - satellite will include baseband processing; that is, frequency dehopping, demodulation, rerouting and remodulation.

d. Cross-links between geostationary satellites and for access to low orbiting or inclined satellites. The cross-link can be either at RF (60 GHZ or greater) or by laser communication.

e. Wideband satellites that can transmit hundreds of mega bits of protected traffic. This could involve laser satellite (LASERSAT) or satellites operating in the EHF band. [Ref. 4]

V. INTERCEPT AND DIRECTION FINDING SYSTEMS

A. GENERAL

Over the last ten years the evolutionary progress made in communication technology transmission methods, modulation waveforms, and communication schemes discussed in Chapter IV has changed the tactical military electromagnetic environment drastically. This situation presents formidable challenges to surveillance receivers and intercept systems. These modern technologies require specialized surveillance systems to counter them. Approaches include microscan, Fast Fourier Transform (FFT) receiving systems, and other types of compressive receivers.[Ref. 6] Changes in the approach to surveillance systems has also brought improvements in the conventional superheterodyne receivers which monitor the communication spectrum. A digitally tuned superheterodyne receiver has fast tuning, wide frequency coverage, the ability to monitor multiple waveforms, programmable search, selectable IF bandwidths, various demodulators and amplitude/phase tracking characteristics which are consistent with DF applications. [Ref. 7]

Like interception and monitoring in communication intelligence, direction finding (DF) is a primary intelligence source for locating enemy communication centers. Generally,

the communication centers are located in close proximity to command posts and command and control nodes, which make them attractive targets for both physical and electronic attack. Similarly, a concentration of emitters within an area may indicate the presence or absence of activities undetectable by other means of intelligence. A typical Direction Finding (DF) system consists of a receiver, DF processor and antenna. A DF system attempts to determine the location of an emitter by measuring the direction of arrival of an intercepted signal.

B. INTERCEPT RECEIVERS

A communication intercept receiver system monitors the frequency spectrum over a pre-defined range and determines the frequency, signal strength, signal type, and the time of any signal present. To do this, the system first carries out a spectral search; also termed a spectral surveillance. This offers an indication of signal activity, usually in the form of a panoramic display. Following the search, and at the direction of the operator, the system analyzes signals acquired. [Ref. 6]

A spectral search consists of two operations: interception and detection. The interception of signals involves the tuning of the receiver detection band to a certain frequency at a time coincident with signal activity at that frequency.

The range of frequencies over which the receiver simultaneously detects all signals present is the detection band. Signal interception does not mean signal detection. In fact, detection depends on the amount of time the signal remains within the detection band. If the detection bandwidth covers the frequency range of interest; the probability of interception depends on two parameters: the data acquisition time and the processing time. The data acquisition time is the time required to evaluate signal activity. The processing time is the time required to perform the necessary post processing. In superheterodyne surveillance receivers, the post processor simply consists of an energy detector followed by a threshold comparator. [Ref. 8]

Signal analysis implies many things. It can be a simple demodulation of a signal, or it can be a detailed spectral analysis of the signal. Also, analysis can involve more exotic processing such as call sign recognition, language recognition and translation. The difference between the analysis mode and surveillance mode is that the analysis mode processes only a received signal over its bandwidth. In surveillance mode, an entire frequency range of interest goes through processing, although not necessarily on all frequencies at once. [Ref. 8]

Modern ESM receivers have extensive emitter libraries, which contain the history of previously identified emitters,

obtained through ELINT and tactical intelligence information of hostile emitters. Received signal parameters like frequency, type of signal, frequency band occupancy, signal strength, duration of transmission and amount of transmission activity. A match between these parameters and the emitter library triggers the analysis subsystem to investigate this signal. [Ref. 9]

Microprocessors, being the heart of the ESM receiver system, perform various functions like

a. Control the receiver functions

b. Perform automatic scanning, signal identification and logging

c. Accept operator commands from the keyboard

d. Output data to the graphic terminal

e. Save and recall pages of information. [Ref. 8]

Advances and improvements in the field of artificial intelligence (AI) have made the ESM system capable of recognizing the patterns. With further developments this will become a common feature of all intercept and surveillance systems. [Ref. 9]

Software controls the receiver by selecting the center frequency, frequency span, threshold level, etc. Under operator command, the receiver operates in one of two modes: manual mode and automatic mode. In the manual mode the operator has direct control of the receiver and selects the

frequency, IF bandwidth, signal identification and emitter logging, by keyboard commands. In the automatic mode, the operator specifies the instructions and the receiver automatically steps through the selected band. Typically, the receiver provides a spectrum analyzer type of trace on the graphic terminal and performs signal sorting, identification, and logging. In addition, the operator can stop between traces and store or recall a trace and then continue scanning. [Ref. 8]

C. DF SYSTEM

Figure 1 illustrates a commonly used direction finding technique: horizontal or azimuth triangulation for determination of an unknown location. Here, two or more DF sites connected by a communication link measure azimuth angles to an emitter. The separation distance of the sites is comparable to the distance to the emitter. [Ref. 7]

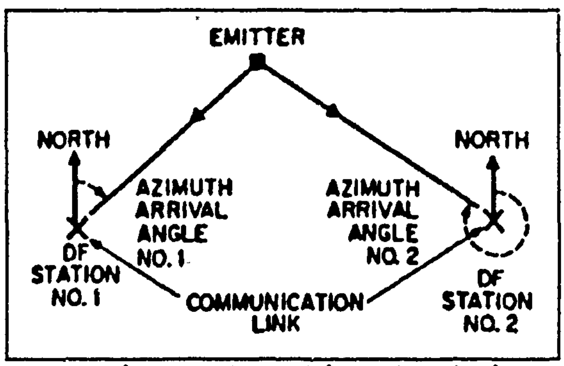

Figure 1 - Emitter location by triangulation

A ground based DF system may be fixed or movable depending upon the operational needs and terrain. A digital computer controls the system, enabling the designer to employ a DF antenna of his choice. The existing real-time signal processing techniques provide both phase and amplitude responses of the received signal, and with proper antennas can respond to signals of any polarization. In the VHF band, antennas having a large electrical aperture are relatively small physically.[Ref. 7]

The processor uses output signal voltages of the receiver system to locate the emitter location. Usually such systems employ modular software, that adapt to a variety of antenna systems and optional capabilities like networking, signal acquisition and monitoring. The system maintains a bearing history for the acquired emitter locations and updates this in case of any change. This helps in correct identification of a previously seen emitter and also serves as a warning in case a new emitter comes up in the threat environment. Typical DF azimuth accuracy achieved by a modern DF system ranges between ±1° to ±3°.[Ref. 9] The following factors are of major importance when planning a DF system acquisition

a. Ground and terrain in which the emitter operates

b. Operating frequencies of the emitter

c. Measurement accuracy desired (this determines the number of DF stations required)

d. Response time (time required to process the signal, match them against the emitter library and display the finished results)

e. Physical limitations of the system. [Ref. 7]

D. CLASSIFICATION OF DF SYSTEM

The technique for obtaining information about the arriving signal at the antenna and the subsequent processing of that information classifies the DF system into two broad categories: scalar systems and vector or phasor systems. If only the direction of the signal of interest is taken into consideration then the system is classified as a scalar system. But, if the system obtains direction and range information about these signals then it is classified as vector or phasor system. In simple terms, the first category of the system deals with either amplitude or phase information of the signal, while the other deals with both information. [Ref. 7]

1. Scalar Systems

Figure 2 shows the rotary loop arrangement employed in most scalar systems.[Ref. 7] Since most of the scalar systems measure the signal strength, they have to rely upon some form of symmetry. Figure 2 clearly indicates this fact where the system depends on the figure of 8 symmetry of its vertically polarized amplitude response. The Adcock and Watson watt antenna systems are examples of such a system.

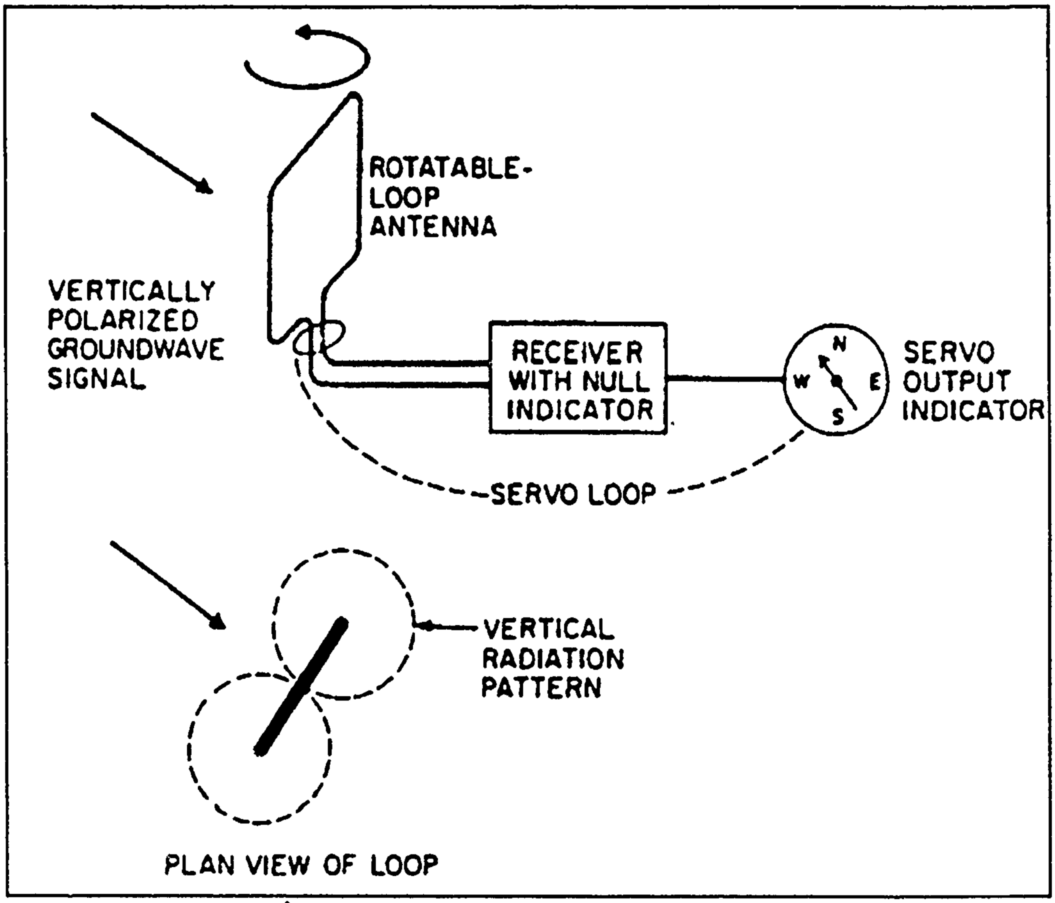

Figure 2 - Rotary Loop System

Systems which deal with the phase information of the signal of interest usually employ multiport antenna systems. Examples are Interferometer and Doppler systems. In vector systems the relative amplitudes and phases measured on different antenna elements uniquely define the bearing, both in azimuth and elevation angles of a single incident plane wave of a specified frequency origination from a source.[Ref. 7]

The two systems (Watkin Johnson and HRB Singer) under evaluation employ interferometer techniques for emitter location. It is worthwhile to describe the technique briefly.

a. Interferometer Technique

One form of this technique uses a small/wide aperture interferometer consisting of three electrically short vertical dipoles (having separation greater than $\lambda/2$) arranged in an equilateral triangle. Centrally located among the feed points of the elements is an enclosure containing a low noise preamplifier for each element. The relative phases measured on these three elements uniquely defines the bearing, azimuth and elevation angles.

The method used in the DF processor to determine a signal's bearing angle involves correlating the complex voltages measured at the antenna elements against a set of stored voltage patterns, each of which corresponds to an incident wave of the same frequency illuminating the antenna

from a different direction. An indicated DF bearing is the azimuth angle that maximizes the magnitude of the complex correlation coefficient. The approach used in such systems is based on a parabolic approximation to wave propagation. [Ref. 9]

2. Vector or Phasor Systems

For emitter location, vector or phasor systems use both amplitude and phase information of the signal of interest. These systems need multiport antennas and at least two amplitude-and-phase-coherent receivers. An extension of vector or phasor systems, termed Wavefront-Analysis (WFA) systems resolve multicomponent wave fields. The main difference between vector and WFA is that WFA require a normal receiver-processor-output system which can determine the incident wave parameters like arriving angles, both azimuth and elevation and relative amplitude and phase. Signals are processed in digital form, thereby fully preserving relative amplitude and phase. Time-difference-of-arrival (TDOA) technique is a good example of WFA DF systems. ESL's system makes use of this technique.[Ref. 7]

a. TDOA Technique

The basic method used to determine the direction to an RF emitter is to measure the time difference of arrival (TDOA) of the RF wavefront between two DF antennas. Figure 3 shows the geometry of the technique.[Ref. 9] It consists

of two antennas separated by a baseline length: d. A wave impinging at an angle ϕ from the normal arrives at antenna B before antenna A by a time difference, ΔT, which actually defines a hyperbola and is determined by

$$\Delta T = t_1 - t_2 = \text{constant}$$

the emitter can be anywhere on hyperbola, hence, usually we need two antennas or more to determine angle ϕ, given by

$$\phi = \arcsin c \frac{\Delta T}{d}$$

where c is the velocity of propagation.

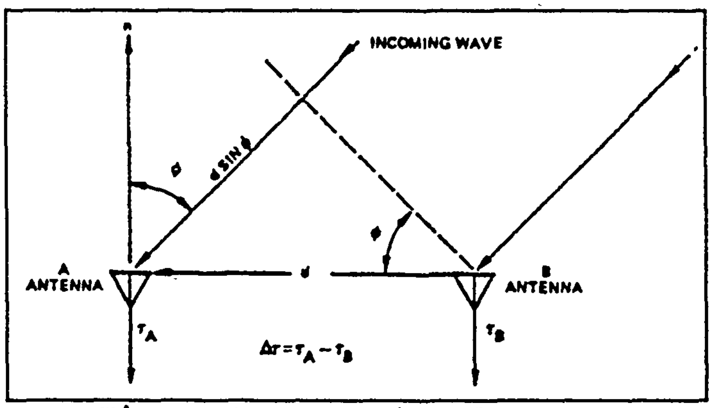

Figure 3 - Geometry for TDOA

Here, it is necessary to measure T accurately to determine the angle of arrival that needs to be measured with an accuracy of hundredths of nanoseconds. To determine an emitter location requires two crossing angles or a minimum of three antennas.

E. ESM SYSTEM IN OPERATIONS OF WAR

In the light of discussion carried out in Chapter III and in this chapter, one can summarize the employment and utility of intercept and DF system in the divisional communication scenario during various operations of war.

1. Defensive Operation

During the initial stages of defense, when the line network is being laid out, VHF radio relay communication is used extensively. The main force uses line and radio relay, but covering troops use radio extensively. Therefore by interception of enemy communication and direction finding his emitters, one not only gains useful information of enemy intentions, rather we can designate air and artillery targets. This information can also help in planning ECM against the hostile emitters.

2. Offensive Operation

During attack, radio becomes the primary means of communication. However, during the advance operation before making contact with the adversary forces, VHF radio relay acts as a backbone for command and control of maneuvering forces. By intercepting enemy communication, we can determine the amount of transmission activity, grouping and regrouping of forces in a particular sector of operation. The direction finding system will indicate the movement patterns of the

emitter, thus enabling us to deduce enemy maneuvers and his intentions.

3. Withdrawal Operation

Radio being the principal means of communication in withdrawal, is subject to maximum exploitation by intercept and DF resources. The movement pattern of emitters can help in determining the enemy's role of withdrawal, allowing the use of air and artillery to jeopardize his withdrawal.

The increasingly dense, complex signal environment demands programmable, high performance ESM systems. Improvements in performance for DF and surveillance applications are achievable, while at the same time maintaining high reliability, small size, and low cost. New technology along with innovative design methods can satisfy the requirements established by the acquisition decision maker and operators.

VI. SYSTEM EVALUATION

A. GENERAL

An evaluation in a defense system's acquisition program should reduce or eliminate the areas of risk. It serves a number of useful functions, providing information about a number of contractors. Evaluation provides information to developers to assist in the identification and resolution of technical difficulties. It also provides information to decision makers responsible for making the investment decision to procure a new system and for deciding on the most effective use of limited resources. Moreover, an evaluation provides information to operational users to support the development of effective tactics, doctrine, and procedures.

For this thesis, letters were sent to sixteen manufacturers actively engaged in developing VHF intercept and DF systems. Appendix A includes a list of all those approached along with their addresses.

Only Watkins Johnson, ESL, Zeeta, HRB Singer, and Napco Internationals responded positively to the request. After reviewing the literature provided by these manufacturers, Watkins Johnson, ESL, and HRB Singer (see the figures in Appendix B.) were selected for the purpose of this evaluation.

The main criteria for their selection was the amount of detailed information provided about their systems.

B. LIMITATIONS

a. The following aspects are not addressed in this evaluation:

    1) Expected threat analysis.

    2) Enemy resources and capabilities.

    3) Existing Pakistan Army EW resources and capabilities.

    4) Signal equipment analysis.

b. The logistic efforts required to support the proposed intercept and DF system could not be evaluated due to insufficient information and time.

c. ECM vulnerability could not be assessed since field tests were not feasible and equipment was not available.

d. Proprietary or security classification constraints on the part of contractors.

C. EVALUATION METHODOLOGY AND CRITERIA*

The following criteria provide the rationale and basis for scoring each evaluation parameter. Each parameter has subcategories scored from 0 to 1.0 with zero being lowest and unity being highest. There are a total of 49 parameters which are scored for a total maximum score of 49 for each

---

* **Most of the material is derived from Reference 10.**

Since every subelement of each parameter significantly effects the mission performance, therefore, they are additive and with equal weights. However if any system offers a capability beyond the threshold setting which results in performance enhancement, then a bonus point in fraction is awarded in addition to highest scoring of one.

1. Performance Characteristics

Acquisition

Frequency coverage	30 MHZ - 300 MHZ Full coverage = 1.0 Partial coverage = 0.5
Dynamic Range	How large is the range of power levels between the processing sensitivity and when the signals become detectable. 60 dB = 0.25 65 dB = 0.5 70 dB = 0.75 75 dB = 1.0
Programmable Search	Can the system be tasked for automatic, prioritized search of the bands of interest? Yes = 1.0 No = 0

Speed

Acquisition	How many signals can be acquired in 5 seconds with energy and parameter measurement performed? Less than 5 signals = 0 1 - 5 signals = 0.25 6 - 10 signals = 0.50 11 - 15 signals = 0.75 Greater than 20 signals = 1.0

Response	How long does it take to process the signals acquired in 5 seconds, match them against the emitter library and display the finished results? Greater than 60 seconds = 0 50 - 60 seconds = 0.25 40 - 49 seconds = 0.50 30 - 39 seconds = 0.75 Less than 30 seconds = 1.0
Parameter measurement	How accurate are the measurements for amplitude and frequency? This is a subjective evaluation of how well the parameter measurements support the system's identification of signals. Very accurate = 1 less accurate = .5 not accurate = 0
Direction Finding	
Speed	How many lines of bearing (LOB) on communication signals can be measured/calculated in 1 minute? 20 LOB/seconds = 1.0 Each signal more than 20, add 0.05; each signal less then 20, subtract 0.05.
Accuracy	How accurate are the communication DFs? ± 3 degrees = 1.0 Each degree better than ± 3, add 0.1; each degree worse than ± 3, subtract 0.1.
DF/acquisition on same mast	Is the DF antenna on the primary acquisition mast? Yes = 1.0 No = 0

Total Assets

Number of Receivers	How many measurement receivers does the system have? 2 receivers = 1.0 Add 0.1 for each additional receiver, subtract 0.1 for each receiver less than 2.
Number of Operator Positions	How many are the operator positions in the system? positions = 1.0 Add 0.1 for each additional position.
Simultaneous Search and Analysis	Can the system search and analyze concurrently? Yes = 1.0 No = 0

Operability

Operator Workload	How well is the display organized to allow the operator to deal with heavy environments? This category is a subjective one. Tradeoffs must be made between the amount of data presented and the clarity of the presentation, making use of multi color schemes, graphics etc.
Control all Assets from	Can the operator effectively Operator Positionutilize all his software controlled system assets from his system workstation or are multiple MMIs required? Yes = 1.0 No = 0

Man/Machine Interface (MMI)	Is the data presented to the operator organized effectively? Is the layout of the operator's controls and tools optimized for convenience and ease of use? Check availability of multiple screens or multiple terminals. This is a subjective evaluation based on the answers to questions such as those listed above.
Measurement Equipment for Communication Signals	Does the system provide for automatic/manual measurement equipment for communications signal parameter measurement? Automatic = 0.5 Manual = 0.5
Supports Recording	Does the system support recording with recorders and operator annotation aids? Does the system support automatic recorder control and logging? Yes to both questions = 1.0 Yes to one questions = 0.5
Response Time	Does the system respond within 1 second to operator initiated commands? Yes = 1.0 No = 0

Operator Aids

Exploitation Aids	Does the system have hardware/software aids which allow the operator to drive signal internal information? Yes = 1.0 No = 0

Bearing History	Does the system maintain bearing history and provide for bearing smoothing on targets? Yes to both questions = 1.0 Yes to one question = 0.5 No = 0
Emitter Libraries	Does the system have an extensive library of known emitters to try to match intercepted signals with? Less than 500 = 0 500 - 1000 = 0.25 1001 - 2000 = 0.5 2001 - 3000 = 0.75 Greater than 3000 = 1.0
Re-acquisition Recognition	Can the system correctly identify a previously seen emitter and tag it with the same detection number? Yes = 1.0 No = 0
Automatic Logging	Does the system automatically log system detections, identifications, and measurements? Can the logs be recalled and reviewed at the operators discretion? Yes to both questions = 1.0 Other = 0
Event Recognition	Can the system recognize that an event is occurring, or about to occur, based on the sequence of emitter detections? Yes = 1.0 No = 0
Tactical Situation Analysis Display	Does the system offer standard military map (Mercator) projections facility? Yes = 1.0 No = 0

Environment Table	Does the system have a large environment table to store information about intercepted signal? Yes = 1.0 No = 0
Automatic File Lookup	Does the system have data base management tools that allow for automatic file search and sort? Yes = 1.0 No = 0

Environment Handling Ability

Multiple Simultaneous Signals	Can the system process multiple simultaneous signals within the same quadrant? Yes = 1.0 No = 0
Environment Table	Is there a separate environment table associated with a receiver group to perform preprocessing to relieve the burden from the main data processing equipment? Yes = 1.0 No = 0
Total Pulses per Second (pps) Handled	What is the total pps processing capability of the system? 100 Kpps - 199 Kpps = 0.25 200 Kpps - 399 Kpps = 0.5 400 Kpps - 800 Kpps = 0.75 Greater than 800 Kpps = 1.0
Process Complex Emitters	Can the system detect and process complex emitter (spread spectrum, burst signal) types? Yes = 1.0 No = 0

2. Design Characteristics

Space and Structure

Space for N-Suite	Does the system have rack space and cable interconnects for the augmentation package? Yes = 1.0 No = 0
Ruggedness	Does the system hardware exhibit sufficient ruggedness to sustain rough handling by men and during transportation? System response to shocks and vibrations? This is a subjective evaluation based on the apparent look of the structure of the system.

Modularity

Extensible Architecture	Can the system architecture accommodate additional receivers and processors to meet the needs of a changing environment, without major redesign? Yes = 1.0 No = 0
Internal Commonality	Does the system make use of common cards and subassemblies as much as possible within itself? Yes = 1.0 No = 0

Operational Supportability

Test Equipment	Does the system have built-in test equipment? Yes = 1.0 No = 0

Technical Manuals	Is the system supported by Military Specified (Operating and Maintenance Instructions, circuit diagrams, etc.) Technical Manuals? Yes = 1.0 No = 0
On-Line PM/FL	Does the system have on-line performance monitoring and fault location? Yes = 1.0 No = 0
Military Specified Construction	Was the system constructed to meet Mil-Spec Requirements? Built to meet = 0.75 Fully qualified = 1.0
Electromagnetic Interference (EMI)	Does the system meet Mil-Spec Requirements for EMI? Yes = 1.0 No = 0
Transportability	Type of vehicle required for installation. In .25 ton jeep = 1.0 In 1.5 ton truck = 0.75 In 2.5 ton trucks = 0.50
Space for other Equipment	Is space left for installation of other augmentation equipment after the basic N-suite is installed? In .25 ton jeep = 1.0 In 1.5 ton truck = 0.75 In 2.5 ton trucks = 0.50
Power	Does the system offer integral power source for use in the field in case of main power source failure. Yes = 1.0 No = 0

Set Up/Tear Down Time	Time required to set up and tear down the system in the field. 20 minutes = 1.0 Each minute more than 20, subtract 0.05; each minute less than 20, add 0.05.
Operating Temperature	Operating temperature range of the system? -5 deg C to 50 deg C = 1.0 0 deg C to 50 deg C = 0.50

3. Multipliers

Link Communication	Does the system offer integrated communication links for the flow of information between master and slave stations? Yes = 1.0 No = 0
Nuclear Survivability	Does the system offer protection against electromagnetic pulse (EMP) effects? Yes = 1.0 No = 0
Credibility	How far along the development cycle of the system? Fielded in U.S. Army = 1.0 Fielded in other army = 0.8 Prototype = 0.7 Brassboard = 0.5

D. SYSTEM COMPARISON

Table I gives an overview of the criteria and their resulting evaluations for all three systems. An asterisk (*) represents a situation where information was not available.

To ensure an unbiased evaluation, a supplementary system comparison sheet is shown in Table II. It includes only those parameters where all three contractors furnished information.

TABLE 1. SYSTEM COMPARISON SHEET

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
PERFORMANCE CHARACTERISTICS						
ACQUISITION						
FREQUENCY COVERAGE	2MHZ-500MHZ	1.0	2MHZ-500MHZ	1.0	0.5MHZ-500MHZ	1.0
DYNAMIC RANGE	70dB	0.75	66dB	0.5	*	-
PROGRAMMABLE SEARCH	Yes	1.0	Yes	1.0	Yes	1.0
SPEED						
ACQUISITION SPEED	More than 20 signals	1.0	*		*	-
RESPONSE TO OPERATOR	less than 30 seconds	1.0	*		*	-
PARAMETER MEASUREMENT	Good	1.0	Good	1.0	*	-
DIRECTION FINDING						
SPEED	20 LOB in 1 minute	1.0	*		*	
ACCURACY	± 3°	1.0	± 2°	1.1	± 5°	0.8
DF/ACQ ON SAME MAST	Yes	1.0	Yes	1.0	No	0.0
DF/INTERCEPT INTEGRATION	Yes	1.0	Yes	1.0	Yes	1.0
TOTAL ASSETS						
NUMBER OF RECEIVERS	1	0.9	2	1.0	2	1.0
NUMBER OF OPERATOR POSITIONS	2	1.0	2	1.0	2	1.0
SIMULTANEOUS SEARCH & ANALYSIS	Yes	1.0	Yes	1.0	Yes	1.0

* Information is not provided by the contractor

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
OPERABILITY						
OPERATOR WORKLOAD	Good	1.0	Good	1.0	*	-
CONTROL ALL ASSETS FROM POSITION	Yes	1.0	Yes	1.0	*	-
MAN/MACHINE INTERFACE	Yes	1.0	Yes	1.0	*	-
MEASUREMENT EQUIPMENT	Automatic/Manual	1.0	Automatic/Manual	1.0	Automatic/Manual	1.0
SUPPORTS RECORDING	Yes	1.0	Yes	1.0	Yes	1.0
RESPONSE TIME	Yes	1.0	Yes	1.0	*	-
OPERATOR AIDS						
EXPOLITATION AIDS	No	0.0	No	0.0	No	0.0
BEARING HISTORY	*	-	Yes to one question	0.5	Yes to one question	0.5
EMITTER LIBRARIES	*	-	600	0.25	*	-
RE-ACQUISITION RECOGNITION	Yes	1.0	Yes	1.0	*	-
AUTOMATIC LOGGING	Yes	1.0	Yes	1.0	Yes	1.0
EVENT RECOGNITION	No	0.0	No	0.0	No	0.0
TAC-SIT ANALYSIS DISPLAY	Yes	1.0	No	0.0	Yes	1.0
ENVIRONMENT TABLE	Yes	1.0	Yes	1.0	*	-
AUTOMATIC FILE LOOKUP	Yes	0.0	Yes	1.0	Yes	1.0
ENVIRONMENT HANDLING ABILITY						
MULTIPLE SIMULTANEOUS SIGNALS	*	-	*	-	*	-
ENVIRONMENT TABLE	*	-	Yes	1.0	*	-
TOTAL PPS HANDLED	*	-	*	-	*	-
PROCESS COMPLEX EMITTERS	Burst Signals	1.0	Spread Spectrum Signals	1.0	*	-

* Information is not provided by the contractor

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
DESIGN CHARACTERISTICS						
SPACE AND STRUCTURE						
SPACE FOR N-SUITE	Yes	1.0	Yes	1.0	Yes	1.0
RUGGEDNESS	Good	1.0	Fair	0.6	*	-
MODULARITY						
EXTENSIBLE ARCHITECTURE	Yes	1.0	Yes	1.0	Yes	1.0
INTERNAL COMMONALITY	Yes	1.0	Yes	1.0	Yes	1.0
OPERATIONAL SUPPORTABILITY						
TEST EQUIPMENT	BITE exists	1.0	BITE exists	1.0	*	-
TECHNICAL MANUALS	Yes	1.0	Yes	1.0	Yes	1.0
ON LINE PM/FL	Yes	1.0	Yes	1.0	*	-
MILSPEC CONSTRUCTION	Built to meet	0.75	Built to meet	0.75	Built to meet	0.75
EMI	Yes	1.0	Yes	1.0	Yes	1.0
TRANSPORTABILITY	1½ ton truck	0.75	1½ ton truck	0.75	2½ ton truck	0.5
SPACE FOR OTHER EQPT	Yes	0.75	Yes	0.75	Yes	1.0
POWER SOURCE	Yes	1.0	No	0.0	Yes	1.0
SET UP/TEAR DOWN TIME	20 minutes	1.0	20-25 minutes	0.7	30 minutes	0.5
OPERATING TEMPERATURE	0° - 55° C	1.0	5° - 50° C	0.4	0° - 50° C	1.0
MULTIPLIERS						
LINK COMMUNICATION	Yes	1.0	No	0.0	Yes	1.0
NUCLEAR SURVIVABILITY	No	0.0	No	0.0	No	0.0
CREDIBILITY	Fielded in other army	0.8	Fielded in other army	0.8	Prototype	0.7
TOTAL		37.7		34.1		23.75

* Information is not provided by the contractor

TABLE 2. SUPPLEMENTARY SYSTEM COMPARISON SHEET

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
PERFORMANCE CHARACTERISTICS						
ACQUISITION						
FREQUENCY COVERAGE	2MHZ-500MHZ	1.0	2MHZ-500MHZ	1.0	0.5MHZ-500MHZ	1.0
DYNAMIC RANGE	-	-	-	-	-	-
PROGRAMMABLE SEARCH	Yes	1.0	Yes	1.0	Yes	1.0
SPEED						
ACQUISITION SPEED	-	-	-	-	-	-
RESPONSE TO OPERATOR	-	-	-	-	-	-
PARAMETER MEASUREMENT	Good	1.0	Good	1.0	-	-
DIRECTION FINDING						
SPEED	-	-	-	-	-	-
ACCURACY	± 3°	1.0	± 2°	1.1	± 5°	0.8
DF/ACQ ON SAME MAST	Yes	1.0	Yes	1.0	No	0.0
DF/INTERCEPT INTEGRATION	Yes	1.0	Yes	1.0	Yes	1.0
TOTAL ASSETS						
NUMBER OF RECEIVERS	1	0.9	2	1.0	2	1.0
NUMBER OF OPERATOR POSITIONS	2	1.0	2	1.0	2	1.0
SIMULTANEOUS SEARCH & ANALYSIS	Yes	1.0	Yes	1.0	Yes	1.0

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
OPERABILITY						
OPERATOR WORKLOAD	-	-	-	-	-	-
CONTROL ALL ASSETS FROM POSITION	-	-	-	-	-	-
MAN/MACHINE INTERFACE	-	-	-	-	-	-
MEASUREMENT EQUIPMENT	Automatic/Manual	1.0	Automatic/Manual	1.0	Automatic/Manual	1.0
SUPPORTS RECORDING	Yes	1.0	Yes	1.0	Yes	1.0
RESPONSE TIME	-	-	-	-	-	-
OPERATOR AIDS						
EXPOLITATION AIDS	No	0.0	No	0.0	No	0.0
BEARING HISTORY	-	-	-	-	-	-
EMITTER LIBRARIES	-	-	-	-	-	-
RE-ACQUISITION RECOGNITION	-	-	-	-	-	-
AUTOMATIC LOGGING	Yes	1.0	Yes	1.0	Yes	1.0
EVENT RECOGNITION	No	0.0	No	0.0	No	0.0
TAC-SIT ANALYSIS DISPLAY	Yes	1.0	No	0.0	Yes	1.0
ENVIRONMENT TABLE	-	-	-	-	-	-
AUTOMATIC FILE LOOKUP	Yes	0.0	Yes	1.0	Yes	1.0
ENVIRONMENT HANDLING ABILITY						
MULTIPLE SIMULTANEOUS SIGNALS	-	-	-	-	-	-
ENVIRONMENT TABLE	-	-	-	-	-	-
TOTAL PPS HANDLED	-	-	-	-	-	-
PROCESS COMPLEX EMITTERS	Burst Signals	1.0	Spread Spectrum Signals	1.0	No	-

EVALUATION PARAMETERS	ESL SYSTEM		WJ SYSTEM		HRB SYSTEM	
	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE	CHARACTERISTIC	SCORE
DESIGN CHARACTERISTICS						
SPACE AND STRUCTURE						
SPACE FOR N-SUITE	Yes	1.0	Yes	1.0	Yes	1.0
RUGGEDNESS	-	-	-	-	-	-
MODULARITY						
EXTENSIBLE ARCHITECTURE	Yes	1.0	Yes	1.0	Yes	1.0
INTERNAL COMMONALITY	Yes	1.0	Yes	1.0	Yes	1.0
OPERATIONAL SUPPORTABILITY						
TEST EQUIPMENT	-	-	-	-	-	-
TECHNICAL MANUALS	Yes	1.0	Yes	1.0	Yes	1.0
ON LINE PM/FL	-	-	-	-	-	-
MILSPEC CONSTRUCTION	Built to meet	0.75	Built to meet	0.75	Built to meet	0.75
EMI	Yes	1.0	Yes	1.0	Yes	1.0
TRANSPORTABILITY	$1\frac{1}{2}$ ton truck	0.75	$1\frac{1}{2}$ ton truck	0.75	$2\frac{1}{2}$ ton truck	0.5
SPACE FOR OTHER EQPT	Yes	0.75	Yes	0.75	Yes	1.0
POWER SOURCE	Yes	1.0	No	0.0	Yes	1.0
SET UP/TEAR DOWN TIME	20 minutes	1.0	20-25 minutes	0.7	30 minutes	0.5
OPERATING TEMPERATURE	0° - 55° C	1.0	5° - 50° C	0.4	0° - 50° C	1.0
MULTIPLIERS						
LINK COMMUNICATION	Yes	1.0	No	0.0	Yes	1.0
NUCLEAR SURVIVABILITY	No	0.0	No	0.0	No	0.0
CREDIBILITY	Fielded in other army	0.8	Fielded in other army	0.8	Prototype	0.7
TOTAL		25.95		22.15		23.25

E. SUMMARY

Tables I and II both show the superiority of the ESL system.

A comparison of total scores in Tables I and II show that the Watkins Johnson and HRB Singer systems change order when the ranking is restricted to available information. This suggests that further consideration of both systems may be necessary.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The fundamental purpose of this thesis is to reduce the risk involved in a VHF intercept and DF system acquisition program if undertaken in the near future by the Pakistan Army. Therefore, the author has evaluated the VHF Intercept and Direction Finding (DF) collection systems developed by three different manufacturers for use by a divisional level signal battalion. This thesis examined systems developed by ESL International, Watkin Johnson, and HRB Singer on the basis of performance, design and supportability issues. The scoring criteria and rationale discussed in Chapter VI of this thesis explains the weighting of each subelement of the intercept and DF system.

From the discussions of EW mission categories, concept of combat communication in a division, modern trends in communication, generic intercept and DF systems, and evaluation process, a number of points should be apparent. First, tactical electronic reconnaissance (ER) is an important activity towards tactical planning and adjustment of EW assets to meet the current threats. Second, a large number of tactical communication systems tend to dominate the VHF and UHF portion of the electromagnetic spectrum. Third, the

expected dense electromagnetic environment heavily taxes the existing intercept and DF collection capability of a divisional signal battalion and demands enhancement of resources. Similarly, an effective use of ECCM by friendly forces should be emphasized to counter the enemy's EW effort, which will be the only difference between winning and losing. Fourth, the armies of developed countries now make effective use of modern communication techniques like spread spectrum, meteor burst communication, fiber optics, etc. Which severely reduces not only the possibility of intercepting and interpreting communications but jamming possibilities as well. The key to secure and reliable communication is having modern covert communication assets within existing financial constraints. Fifth, the modern intercept and DF systems employ novel ideas which offers dependable and reliable signal detection, identification, location, and analysis procedures. The procedures followed are software oriented. The software can be changed to enhance the system performance keeping the hardware intact. Sixth, fully automatic systems are one or two orders of magnitude faster and more accurate than manual systems. Finally, the objective evaluation of an intercept and DF system leads us to the conclusion that the ESL International system should meet the mission and operational requirements of a divisional signal battalion under current threat environments.

B. RECOMMENDATIONS

This thesis offers the following recommendations:

a. The intercept and DF system developed by ESL meets the mission needs of a divisional signal battalion in the current threat environment.

b. An intercept and DF platoon equipped with the selected system should be integrated as an integral part of the radio company of a divisional signal battalion.

c. The introduction of a new system will affect the tactical doctrine and concept of combat communication at divisional level. Therefore, in addition to the operational test of the system, the operational test (OT) team should perform the following:

   1) Study the affect on tactical doctrine and concept of combat communication in a division.

   2) Assess the impact on the Table of Organization and Equipment (TO&E) of signal battalion and suggest manpower increase required to achieve the desired performance objectives.

   3) Analyze and determine the compatibility of the new system with the existing resources of a signal battalion to take care of divisional intercept and DF needs.

   4) Assess the impact of the system operation and maintenance, and evaluate the need for additional training, associated publications, training aids and time.

   5) Confirm the system parameters chosen in this thesis work under real field environments.

d. Before the operational test is carried out, the contractor should be asked to provide the following:

   1) Operator training

   2) Maintenance training

   3) Operator and maintenance manuals

4) First echelon to depot level maintenance support

e. The system should be hardened to survive a nuclear electromagnetic pulse.

f. The contractor should be responsible for system engineering and maintenance support for the first year after the installation of the system.

g. A feasibility study should be carried out to assess the suitability and affordability of having secure fiber optic links from division to corps and corps to army headquarters.

APPENDIX A: LIST OF MANUFACTURES

NAME	RESPONSE
Marconi Defense System Ltd Browns Lane, the Airport, Portsmouth Hampshire P03 5PH, England	
Plessey Military Communication Southleigh Park House Eastleigh Road, Havant Hampshire P092PE, England	
Racal Communication, Inc 5 Research Place Rockville, MD 20850	
Columbia Electronics International Inc 3301 West 5th St., PO Box 5066J Oxnard, CA 93031	
Napco International Inc Defense Electronic Division 1600 2nd Street South Hopkins Minnesota 55343	X
Cimsa/Sintra Asnieres 19-12 Avenue de l'Europe, BP 44 78140 Velizy-Villacoublay France	
AEG Aktiengesellschaft Defense Technology Theodor-Stern-Kai 1-3 D-6000 Frankfurt 70 West Germany	

NAME	RESPONSE
Rodhe & Schwarz GmbH & CO KG Postfach 80 14 69 D-8000 Munich 80 West Germany	
Siemens AG Postfach 23 48 D-8510 Fuerth West Germany	
MBLE (Philips & MBLE Associated SA) Rue des Deux Gares 80 B-1070 Brussels Belgium	
SIEL Industrie Per Lospazio E Le Communicazioni SpA Viele Machinavelli 50125 Firenze Italy	
ESL International Inc 3052 Bunker Hill Lane P.O.Box 4353 Santa Clara, CA 95054-4353	X
Watkins Johnson Company CEI Division 700 Quince Orchard Road Gaithersburg, MD 20878	X
Rockwell International P.O.Box 56356 Dallas, Texas 75356	
Regco 2351 Research Boulevard Rockville, MD 20850	
HRB Singer P.O. Box 60 Science Park Road State College PA. 16804	X

APPENDIX B FIGURES

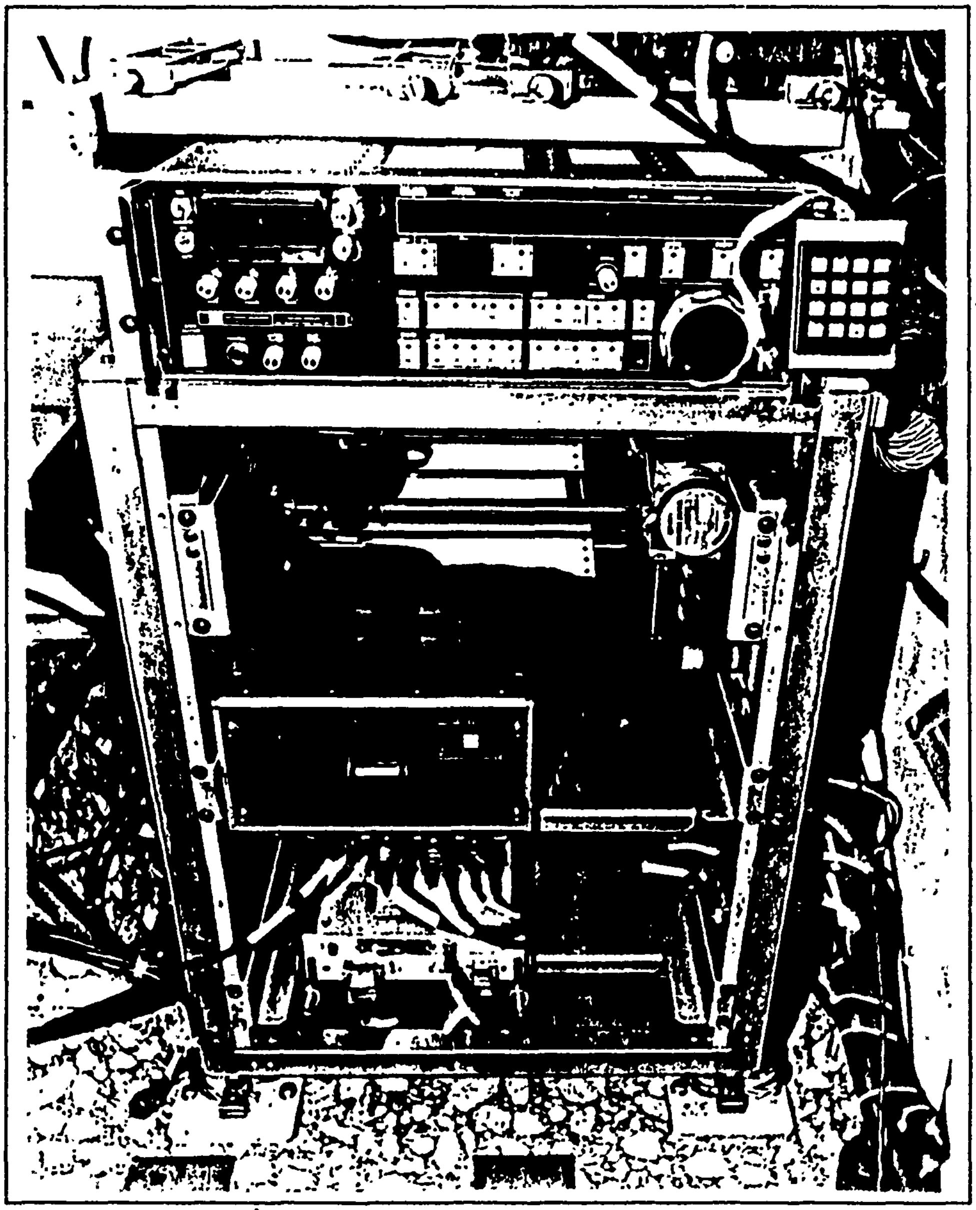

Figure 4 - ESL COMINT SYSTEM

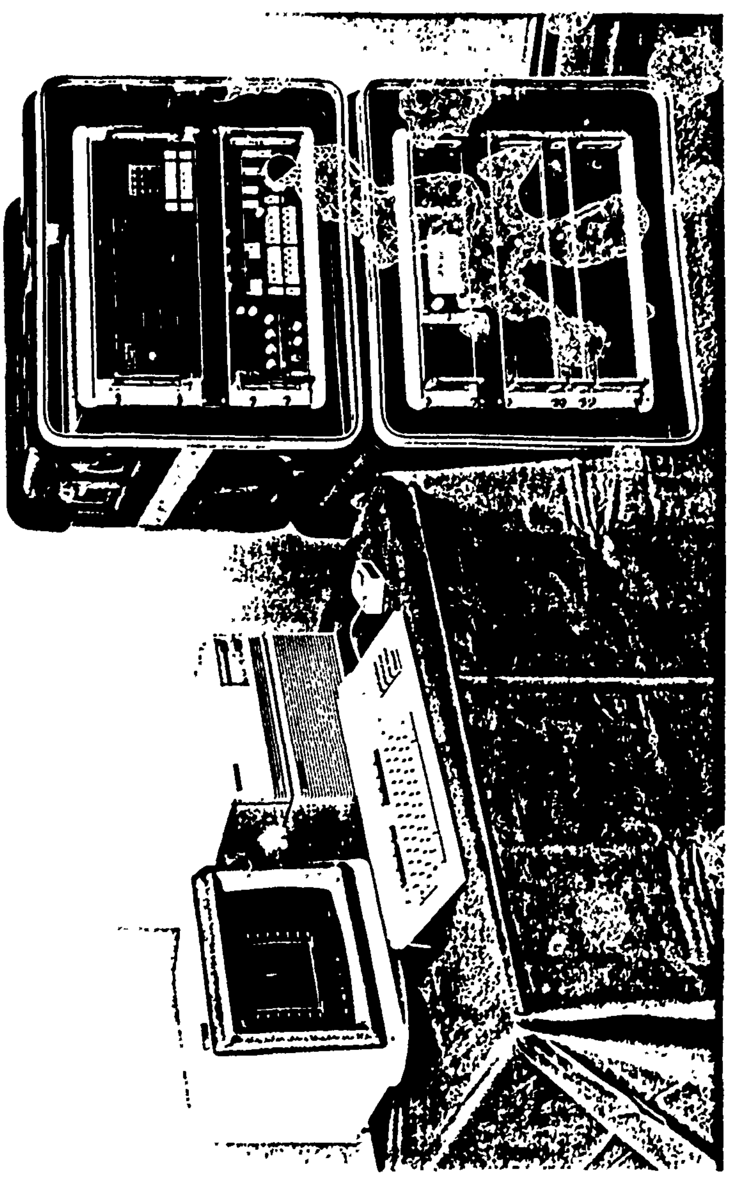

Figure 5 - WJ COMINT SYSTEM

LIST OF REFERENCES

1. Masters, George W., "Electronic Warfare Systems Test & Evaluation". U. S. Naval Test Pilot School Research Report, pp. 2.0-2.14, 1981.

2. Streetly, Martin, "Electronic Reconnaissance and Threat Warning System". Airborne Electronic Warfare, pp. 120-154, 1988.

3. Torrieri, Don J., "Pseudonoise Spread-Spectrum Systems", Principles of Military Communication Systems, pp. 23-60, 1981.

4. Ricci, Fred J., and Schutzer, Daniel, "Future Technology Opportunities", U. S. Military Communication, pp. 194-214, 1986.

5. Trenholm, Paul A., "Fiber Optics - Wire of Future/Present" International Countermeasure Handbook, pp. 384-398, 1980.

6. Drapac, Michael J., "Advances in ESM Receiver Technology" Journal of Electronic Defense, pp. 83-87, 4/87.

7. Kennedy, Hugh D., and Wharton, William, "Direction-Finding Antennaes and Systems", 39.2-39.31, Technology for Communications Internationals, September 1985.

8. Mudry, Andrew, "Dynamic Range Consideration in Superhectodyne Receivers", Defense Research Establishment - Ottawa Technical Note, pp. 1-6, 9/88.

9. Naval Postgraduate School class lectures delivered by J. Adler on "Signal Intelligence" during July-September 1989 academic quarter

10. Stidolph, Donna, "Notes on ESM and ECM System Evaluation", GTE Government Systems.

BIBLIOGRAPHY

Jacob, G., "Pakistan Army". Asian Defense Journal, pp.4-22, 8/85.

Witt, Mike, "Electronic Warfare - Why and How", Asian Defense Journal, pp.52-62, 1/81.

Van Kirk, Robert C., "Electronic Warfare Training in the U.S. Army", Journal of Electronic Defense, pp. 49-68, 9/10 1981.

Gibbs, George, "Communication Electronic Warfare", Asian Defense Journal, pp 78-81, 2/87.

Hovanessian, S.A., "Noise Jammers as Electronic Countermeasures", Microwave Journal, pp. 113-124, 9/85.

Boyd, J. B., Harris, D.B., and Welch, H. W., "Characteristics of Electronic Countermeasure", Electronic Countermeasures, pp. 1.1-1.25, 1961.

Surtis, Schleher D., "Electronic Warfare Principles, Electronic Countermeasures, Electronic Counter Countermeasures", Introduction to Electronic Warfare, pp. 1-24, 109-130, 1986.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library Naval Postgraduate School Monterey, California 93943-5000	2
3.	Donald L. Walters, Code 61We Department of Electronic Warfare Naval Postgraduate School Monterey, California 93943-5000	1
4.	Dan C. Boger, Code 54Bo Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5000	1
5.	Maj Aleem Siddiqui 27 Rajput Colony Jehangir Road Chakalala Rawalpindi Pakistan	4
6.	Capt Issam Almetlaq P.O. Box 345 Sult Jordan	1
7.	LTjg Chia Hua Kai ROCN #9 Lane 6, Shy Jain Li Chy Jin District, Kaohsiung 80504 Taiwan, Republic of China	1
8.	Electronic Warfare Directorate Naval Headquarters Islamabad Pakistan	1